ESTIMATION OF THE PRIMARY PRODUCTIVITY OF THE HUNGARIAN SECTION OF THE RIVER DANUBE

(DANUBIALIA HUNGARICA LXX)

by

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Introduction

Oxygen metabolism has a vital function in the energy- and material household of waters. Measure and dynamics of oxygen metabolism in the ocean and in stagnant freshwaters have been examined very intensively in the last decades and a vast amount of systematized knowledge has been gained.

Researches into the oxygen metabolism of running freshwaters, however, are recent and less in number. This is a consequence of the great number of difficulties which have to be surmounted if one wants to follow the oxygen metabolism in running, moving, constantly mixed water, i.e. if the determination of the amount of metabolic products moving along with the water is aimed at.

The light-and-dark-bottle method is extensively used for the determination of the primary production of stagnant waters by measuring either O_2-concentration or ^{14}C activity. The determination of primary production in running waters is more complicated as it changes with space and time; besides the light-and-dark-bottle method, the "spot method" (Odum 1956), the analysis of diurnal oxygen data measured at one or two stations along the river (Odum 1956) and the wide variety of evaluation possibilities of oxygen plots (Brujewicz 1936, McConnell 1962) should be mentioned. Unfortunately none of these methods is accurate, when using them theoretical concessions are unavoidable or invalid generalizations are required, different processes within the time of measurement can only be determined jointly; these are the reasons why all examinations on primary production give only estimates.

During the examination of nonflowing waters primary production is evaluated usually in terms of the amount of organic carbon formed (calculated sometimes as glucose) or expressed as energy since the produced organic matter ensures the nutrients in the water. If considered in the aspect of running water view primary productivity means the O_2-content produced by phytoplankton organisms during the unit of time (expressed in some cases for water flow during the unit of time), which ensures the "biogenous ventilation", i. e. self-purification possibility of the river.

At the estimation of primary production a clear distinction should be made between *gross productivity* and *net productivity:* "The gross productivity is the rate of production of new organic matter, or fixation of energy, including that subsequently used by the plant and lost as carbon dioxide and heat; that is, the observed change in biomass plus all losses, including respiration, divided by the time interval. The net productivity is the rate of accumulation of new organic matter, or stored energy; that is, the observed change in biomass plus all losses except respiration, divided by the time interval. The net production is the organic material or energy available for exploitation by secondary producers or consummers." (Westlake 1965). By *respiration* the joint respiration of algae and heterotrophic organisms is meant, i.e. the respiration of the biocenosis as a whole. *Diffusion*, i.e. the physical O_2-exchange between water surface and air, often neglected in case of stagnant waters, is very important with rivers. Some of the authors use an individual estimation of diffusion (Odum 1956, Odum – Hoskin 1958, Edwards – Owens 1962, Wright – Mills 1967) while others are of the opinion, that the effect of gas exchange at the surface of the water is diurnally compensated and should be taken into account only in case of very asymmetrical O_2-curves (Müller – Knöpp 1971).

The Danube Research Cooperation of the SIL begun estimating the primary production of the Danube in 1961 for the German section (Knöpp 1965, 1967). A continuation of this work for the Austrian (Knöpp 1967), Czechoslovak (Ertl – Juris 1967), Hungarian (Knöpp – Dvihally 1971, Dvihally 1971) sections as well as for the Danube delta in Roumania (Olteanu 1970) followed later. The primary production of the Yugoslavian, Bulgarian and USSR sections of the Danube has not been estimated yet.

Method

In this study the primary production of the Danube has been estimated on the basis of one year's measurements made at Paks (110 km. southwards from Budapest, 1531 fluvial km. from the Danube estuary). The water of the main arm was analysed every second month and the obtained data were evaluated (1) by Odum's (1956) single-curve method, i.e. O_2-changes in the water were determined every second hour in a 24 hrs. interval. At the same time (2) unfiltered water was incubated in dark (wrapped in aluminium fol) and light glass bottles of abt. 125 ml. vol. Two parallel tests were made and the initial and final (i.e. after 24 hrs.) O_2-concentrations determined. The dark and light bottles were incubated at different depths (from the surface to the bottom) of the river. The difference of the average O_2-content in the light and dark samples incubated for 24 hrs. can be considered the gross production. Net production can be calculated by Miller and Knöpp's formula (1971)

$$\text{net production} = \text{gross production} - \frac{\text{biochemical oxygen demand}}{2}$$

Biochemical oxygen demand (BOD) can be calculated as the difference between initial oxygen content and the oxygen content after 24 hrs. of dark incubation. BOD, if given on a 24 hrs. basis, is numerically equal with the respiration. Diffusion has been disregarded during calculations.

Results and discussion

Light intensity, temperature of the air and water, oxygen concentration and the corresponding degrees of saturation are plotted in Fig. 1. for every second hour during the 24 hrs. interval (Odum's single curve method for the estimation of production).

Curves resulting from the observations conducted by only one station can be evaluated for production only if the mass of water coming to the site of sampling has undergone in its entire volume the same changes at the time of investigation; the curves themselves will be analysed in detail elsewhere (Dvihally 1973), they are published here only for the sake of compareison and descriptiveness.

Estimations on the primary production founded on light-and-dark-bottle incubation tests are presented in Table I. The data refer to the production of phytoplankton organisms; O_2-production of the periphyton and bentos organisms can be neglected in the Danube. The highest production data can be measured during the summer- and autumn investigations: still, from the averages referred to depth it can be seen that also production near the bottom is significant throughout the year. This is undoubtedly a consequence of turbulence.

In Table II. some data referring to the primary production of the Danube as a whole have been assembled. Though these tests were made at different times and in different hydrographic conditions of the river, some generalizations are still possible. In the German section of the Danube, above Kelheim, primary production is significant. There the river belongs to the oligo- β-mesosaprob type, the water is very clear and transparent, the entire depth (2. m. on an average), is well illuminated; consequently primary production is significant even at the bottom. Downstream from Kelheim primary production varies to a considerable extent; variations are closely correlated with the quality of the water: e.g. below Kelheim and Engelhartszell where there is an accrual of toxic, polluted industrial sewage primary production drops distinctly. Further downstream the temperature of the water rises, the flow velocity of the river decreases, the water becomes richer and richer in nutrients, con-

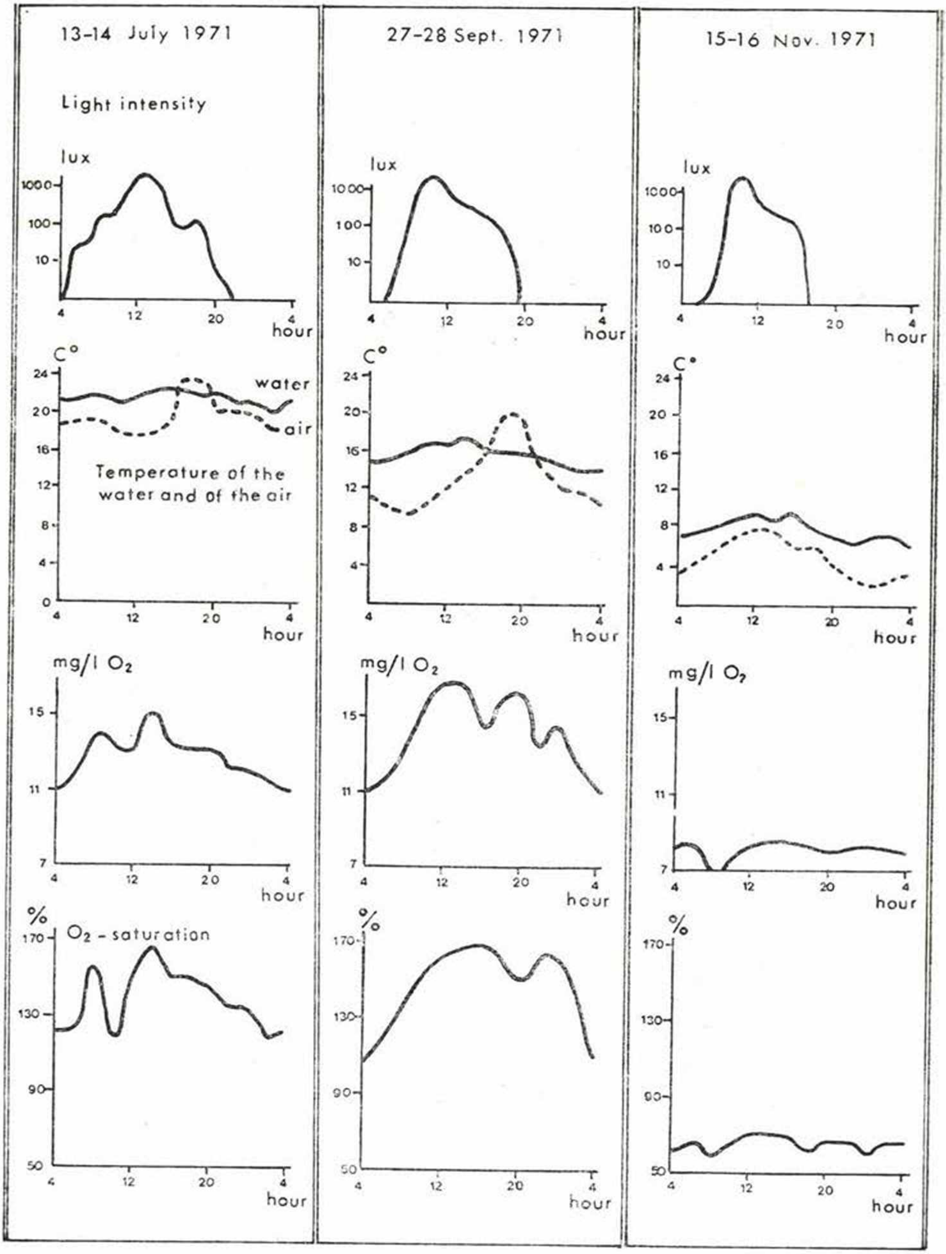
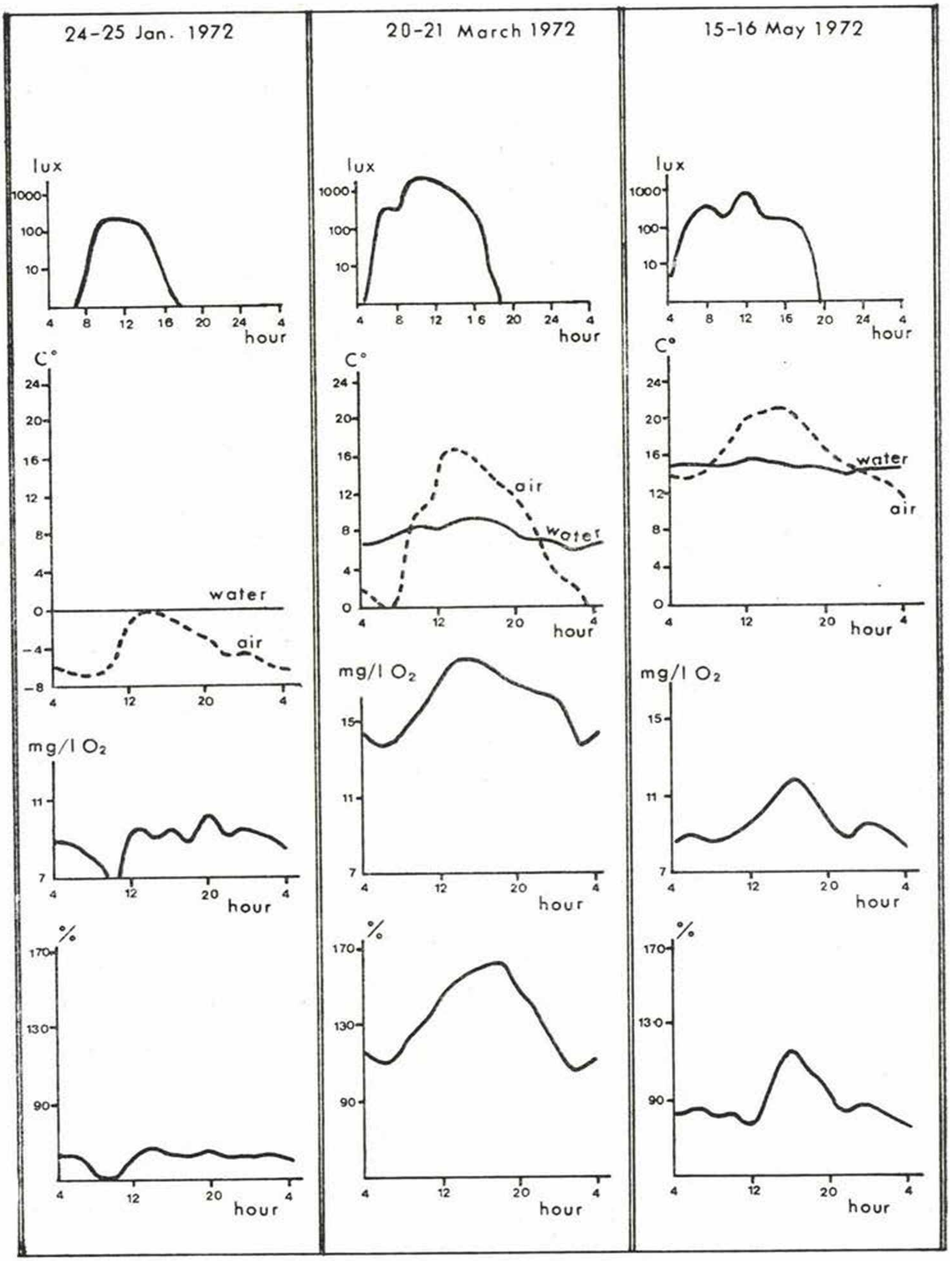


Figure 1. Illumination, temperature of air and water as well



as O_2-concentration in the Danube during the experiments

Table I.

Surface and average primary production (referred to depth) of the Danube.

	13–14. 7. 1971	27–28. 9. 1971	15–16. 11. 1971	24–25. 1. 1972	20–21. 3. 1972	15–16. 5. 1972
Surface						
Gross primary production (P)	2,9	5,1	0,4	–	0,5	0,6
Net primary production	0,0	3,8	0,2	–	0,0	0,0
Respiration (R)	6,0	2,7	0,4	4,6	3,1	1,9
P/R	0,5	1,9	1,0	–	0,2	0,3
Average (on water depth)						
Gross primary production (P)	1,2	5,0	0,4	2,3*	0,0	0,3
Net primary production	0,0	3,6	0,0	0,3*	1,2	0,0
Respiration (R)	2,9	2,8	0,9	4,6	2,3	1,8
P/R	0,4	1,7	0,5	0,5*	–	0,2

* bottom

sequently more and more heterotrophic and productive. Both the surface data and the average values indicate this increasing productivity.

The energy- and material household of the dead arms and side-arms or delta lakes which do not get at all or only at times of floods in contact with the main arm, is entirely different from that of the river itself. Due to the slow or even discontinued flow in these stretches, the float rubble deposits, the temperature and transparency of the water change, a rich living community and soon a nutrient basis is developed in them. These side waters have a vital producing and storing function in the river and – in case of floods, when they get in direct contact with the main river – greatly increase its energy- and material household. The middle and especially the lower stretches of rivers are followed by such side waters of considerable extension: e.g. approx. 20–25% of total area of the Hungarian Danube has a side-arm character. The primary productivity of these waters is a multiple of that of the river itself.

In Table III. the daily O_2-production of the examined cross section is given. This absolute value distinctly shows the immense value of production in the river.

The primary production of the Danube and other rivers are compared in Table IV. , founded on data of the pertinent literature. Only estimations based on O_2-examinations have been taken into consideration here. It appears that as compared to the other rivers examined the productivity of the Danube is moderate.

Table II.

Estimations on the primary production of the Danube founded on references in the literature

primary production
g O_2/m^3 day

	Surface	Average (on water depth)	Reference
German Danube			
above Kelheim	5,4	2,6	Knöpp 1967
below Kelheim	0,2	0,02	Knöpp 1967
below Isar estuary	9,91	2,5	Knöpp 1967
between Kelheim – Jochenstein		1,5 – 2,5	Knöpp 1967
at Straubing	< 0,3	1,1	Knöpp 1967
at Deggendorf	7,1	2,1	Knöpp 1967
Austrian Danube			
at Engelhartszell	0,9 – 1,0		Knöpp 1967
at Aschach	1 – 19		Knöpp 1967
above Vienna	0,0 – 5,2		Knöpp 1967
Czechoslovakian Danube		0,88*	Ertl, Juris 1967
Hungarian Danube			
at Paks	0,4 – 5,1	0,0 – 5,0	
side arm at fkm 1718	10,6 – 19,3		Knöpp, Dvihally 1971
dead arm at fkm 1503	3,5 – 34,6		Knöpp, Dvihally 1971
Roumanian Danube			
lakes of the Danube delta	1,6 – 91,4**	0,38 – 3,54**	Oltean 1970

* annual average
** net productivity

Table III.

Estimation of the diurnal production of O_2 by phytoplankton organisms in the cross section of the Danube at the 1531 fkm.

	Primary production (O_2)
13 – 14. 7. 1971	428 metric tons/day
27 – 28. 9. 1971	400 metric tons/day
15 – 16. 11. 1971	30 metric tons/day
20 – 21. 3. 1972	40 metric tons/day
15 – 16. 5. 1972	123 metric tons/day

Table IV.

Estimations on primary production at the surface of different rivers, relying upon literary references (g $O_2/m^2 \cdot$ day, corrected by the average depths).

Gross primary production

River	min. – max.	Average	Reference
Raritan (N. J. USA)	2,5 – 25,1	4,7 – 11,6	Flemer, 1970
Klyazma (USSR)		2,4	Brujewicz, 1931
Volga at Saratov (USSR)		1,01	Pyrina, 1959
Orinoco (Venezuela)		0,20	Hammer, 1965
Wisla estuary (Poland)		5,27	Javornicky, 1966
Mosel (dammed) (GFR)		20 – 30	Knöpp, 1967
Ivel (GB)	3,2 – 17,6		Edwards, Owens, 1962
Silver Springs (Florida, USA)	8 – 35		Odum, 1956
White River (Indiana USA)		0,24 – 57	Denham, 1938
Itchen River (GB)	0,4 – 14,0		Butcher et al. 1930
River Lark (GB)	0,5 – 39		Butcher et al. 1930
German Danube	5 – 7		Knöpp, 1967
Hungarian Danube	1 – 15		

The toxication of the biogenous oxygen household of the Danube and the rivers highly loaded with industrial sewage can be well compared. The selfpurification capacity of the rivers Rhine and Main is much more deteriorated than that of the Danube (Knöpp 1967) (though the burden of industrial sewages has increased since the time of the measurements and may have caused a deterioration in the Danube too). The examination of the primary production in the Danube is important not only in the immediate vicinity of industrial centres; the undisturbed metabolic processes in the not yet contaminated sections may serve as a good comparative basis for a survey on the possible consequences of the irresponsible management with one of the most valuable natural resource – freshwater.

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Summary

The primary productivity of the Danube at different depths near Paks (1531 fluvial km.) was estimated for a one-year period with the dark-light bottle techique. The results are compared with similar estimations made in other sections of the Danube and in rivers throughout the world; relying upon the comparison the Danube is actually a relatively uncontaminated river of moderate productivity. The importance of side arms in the production of rivers is emphasized.

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